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Offshore Structures

Constructions en mer

Bauwerke im Meer

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INTRODUCTION

With an ever-expanding world population the demands for space, food and energy are increasing annually. This development has caused world-wide concern since the world's land area only covers about three tenths of the earth. Therefore, with the on-shore resources gradually being depleted, growing attention has been focused on the part of the world covered by the oceans. Although studies have been carried out regarding the use of the sea for habitation, so far the main efforts have been directed to exploring the mineral resources beneath the sea. In man's quest to explore these riches, the Continental shelf - the portion of the sea floor less than 200 m below sea level - has become the initial proving ground of the structural engineer, thereby moving gradually from shallow to deeper waters. However, the development of these regions has been rather slow because of the high cost of exploration and production, and the complexity of the associated engineering problems. By early 1974, of the 27,876,000 square kilometers of ocean with depths of 30 m or less, about 60% had shown sedimentary basins potentially holding oil and gas deposits. Of this portion only 25% had been leased for exploration and actually only 15% of that has been explored.

During the sixties the offshore industry has been rapidly expanding to meet world energy demands. In 1960 there were only three of four countries and about five companies with offshore petroleum interests. Fourteen years later several hundred companies are exploring the Continental shelves of 80 countries and already 30 nations are producing, or about to produce, subsea oil and gas. Over 10,000 wells have been drilled offshore and oil and gas are being piped from as far as 400 kilometers offshore and in water depths of up to 150 m. Figure 1 shows the potential offshore oil areas around the world and the locations with current production. With the 1973 increases in the posted price of oil, the economic feasibility of offshore oil and gas exploration and production has improved drastically, unfortunately thereby contributing to an almost rampant world-wide inflation. As a result the expected production rates for the next decade will increase exponentially, as shown in Table I.

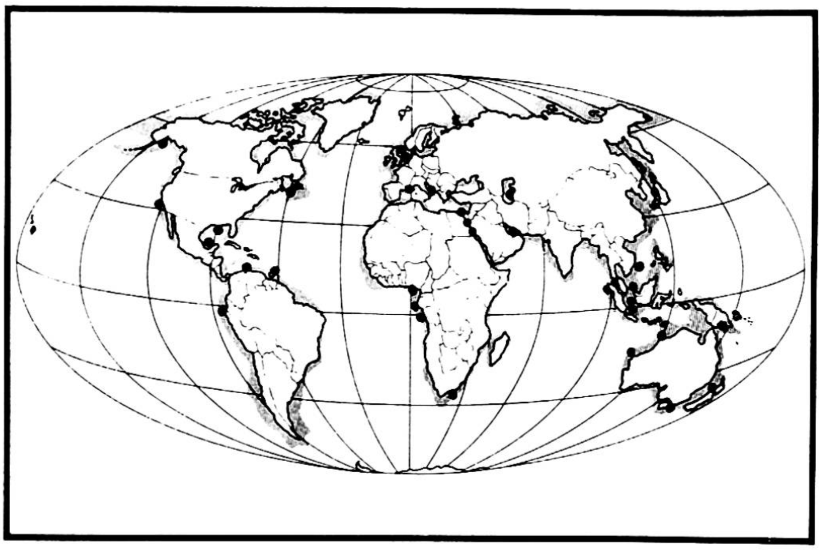

Fig. 1. Regions with offshore oil and gas

In the search for hydrocarbons the objectives of oil companies are the location of promising geological structures, the testing of these structures and the development of successful finds of oil and natural gas. It is realized that deepwater terminals and other near-shore structures may qualify as offshore structures. However, this paper will deal specifically with a discussion of structures which are used in the search and development, or in the exploration and production of hydrocarbons. Associated structures, like offshore storage facilities and underwater pipelines will also be reviewed briefly. Because of the nature of the environment the role of the naval architect in the conceptual design of certain structures is significant. However, because of his particular training, the final formulation of the design configuration is almost exclusively the task of the structural engineer.

Since this paper is a review paper the author decided first to acquaint the reader who is unfamiliar with this field of engineering with the basic types of structures operating in the offshore environment. Subsequently, a discussion of the problems associated with the analysis and design of these structures will be presented.

TABLE I - WORLD OFFSHORE PRODUCTION

YEAR	OIL million bbl/day	GAS billion cu ft/day
1974	8	28
1979	15	59
1984	30	114

OFFSHORE STRUCTURES

Based on the sequence of offshore developments, offshore structures can be grouped in two major categories, namely mobile drilling rigs and production platforms. A third group involving structural engineering could be identified as oil transportation equipment like offshore oil storage facilities, pipe-laying barges and pipelines.

MOBILE DRILLING RIGS

The offshore industry recognizes three types of mobile rigs, namely drillships, jack-ups and semi-submersibles. These units are normally used in the exploration of specific regions of the continental shelf. The jack-up platforms have an operational depth limit of maximum 90 m. For exploration at greater depths the industry uses drillships and semi-submersible drilling rigs. While the advanced units of these latter types have been designed to operate in water depths of 300 m, some of the latest designs have even specified operating depths as large as 600 m. These units are equally suited for operation in calm seas. However, in heavy seas the semi-submersible rigs, because of the partial submersion, provide a more stable drilling platform than the drillships. The roll and pitch of the drillship in heavy weather may force halting the drilling operation.

The cost of these mobile drilling units has lately increased considerably, due to both inflation and more stringent design criteria. Jack-up rigs are now costing between $14 and $18 million and drillships may vary in cost between $20 and $30 million. Finally, the advanced semi-submersibles may run as high as $35 to $40 million. The world-wide inflationary trend has also affected the day rates for these units. A couple of years ago a mobile rig could be contracted at a daily rate of about one thousandth of the initial cost of the equipment. Recently this rate has increased to $1,500 per one million dollar initial cost.

The design of the drillship is of course entirely the domain of the naval architect. However, the design of the jack-ups and semi-submersibles is a joint effort. While the naval architect is responsible for developing the seagoing characteristics of these units, the structural engineer is normally called upon to carry out the structural design of these rigs. Therefore, in the following sections only the jack-up and semi-submersible drilling units will be discussed.

Jack-up Drilling Platforms

The jack-up, or self-elevating platform, typically consists of a floating cellular hull with retractile legs. While enroute the legs are raised as high as safely possible to limit the drag. On site, the legs are lowered onto the seabed and allowed to penetrate while the hull is being raised out of the water. The major structural feature of these rigs are the legs. These units are mostly three or four legged and are presently designed to operate in water depths of up to about 110 m. Conceptual designs have been developed whereby a two-level jack-up and hull system would allow operation in water depths of about 175 m.

One of the larger typical jack-up rigs is shown in Fig. 2. This unit with a hull measuring approximately 70 m x 60 m x 8 m has three legs with a maximum length of 135 m. The maximum operating depth is 90 m with a 9 m leg penetration and an air gap between the water and the bottom of the hull or platform of 15 m. The legs of this rig are oriented vertically and are constructed as welded steel tubular trusses with a square cross-section. While most platforms have vertical legs, some rigs have slanted legs. Others again have tubular trussed legs triangular in cross-section. In some instances the legs are single thick-walled steel columns, either square or circular in shape.

While most of the jack-ups have to be towed, Fig. 3 shows a self-propelled jack-up, the first of its kind. The vessel-shaped hull measures 85 m in length and 40 m in beam. The four tubular trussed legs of triangular cross-section have a length of 108 m and allow operation in water depth of up to 76 m.

Fig. 2. Jackup Drilling Platform

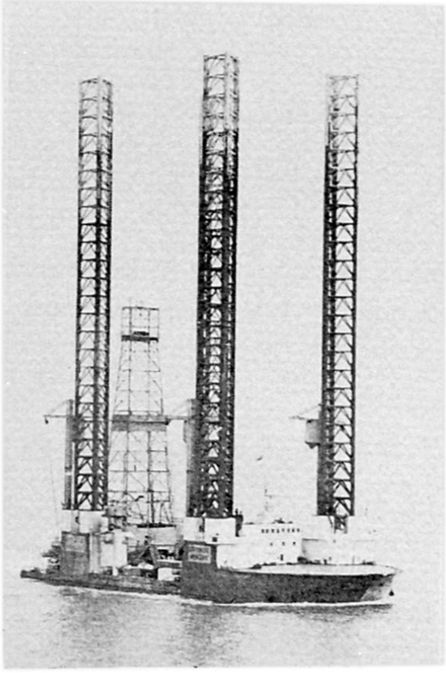

Fig. 3. Self-propelled Jackup

In general, the legs of these jack-ups reach their full length by adding on leg extension sections. These truss extensions are not used when the rig operates in shallower waters. The operating depth for these units, as listed by the owners, entirely depends on the prevailing sea conditions used in the design (maximum design wave, wave spectrum and current). Operating these rigs in a more hostile sea environment requires a reduction of the effective operating depth, not only to achieve an adequate air space but also to maintain the original life-expectancy of the unit. For instance, the deepest rated jack-up rig built to date was specifically designed to meet the stringent requirements of the Norwegian North Sea and can drill in 91.5 m of water during the summer and 84 m during the winter. Operating in other areas, with less severe environmental conditions, additional leg sections can be added to increase the operational water depth to 108 m. The three almost 135 m long slanted legs supporting this unit are square in overall cross-section and have pointed spud cans designed to obtain sufficient penetration and reduce scouring effects on the North Sea floor.

Semi-Submersible Drilling Rigs

The development of semi-submersibles during the last 10 years has shown an evolution from the pontoon-supported, multiple-column stabilizing units to the present-day twin hull rigs. The semi-submersible platform gains its main source of buoyancy from the pontoons or hulls which are submersed below the surface where wave action is less severe. Stability is provided by the vertical columns which pierce the water plane.

Some of the earlier units (1966) were pontoon supported and had three stabilizing columns as shown in Fig. 4. These units were designed to operate in water depths of up to 180 m. More advanced units having the same basic geometry have been designed to operate in depths of 245 m. These rigs have hull dimensions of about 100 m x 100 m. In addition to these units with triangular

Fig. 4. Pontoon-supported Semi-submersible

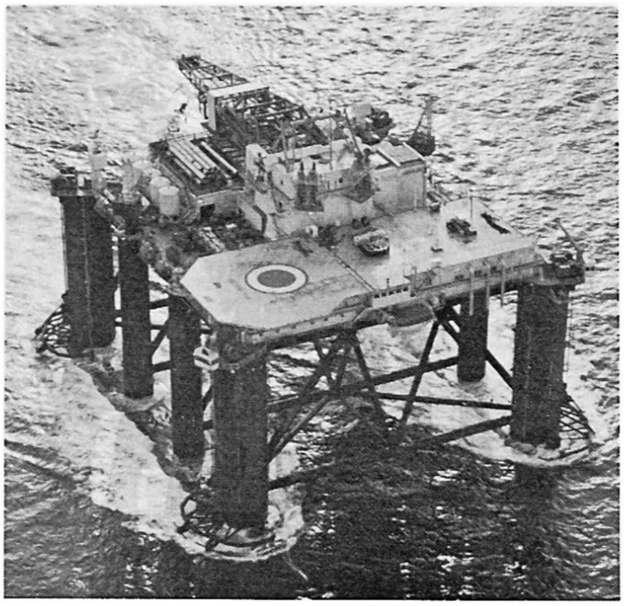

Fig. 5. Twin-hull supported Semi-submersible

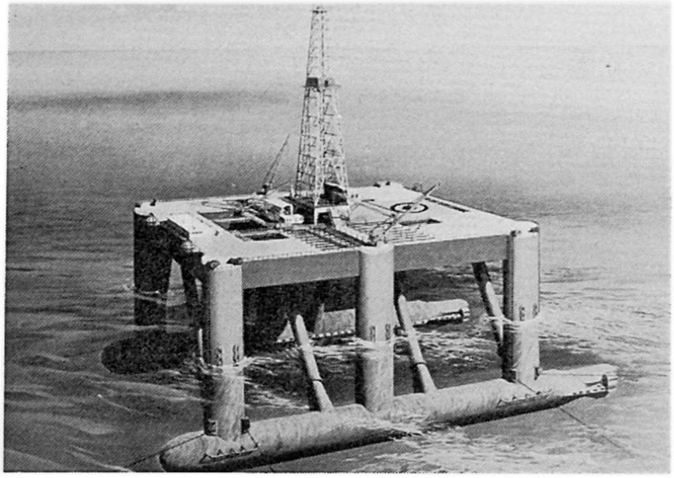

Fig. 6. Twin-hull Self-propelled Semi-submersible

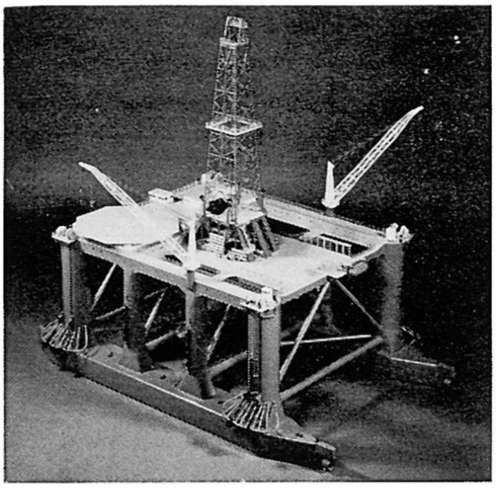

Fig. 7. Twin-hull Self-propelled Semi-submersible

column layouts, other recently built platforms have pentagonal pontoon-supported column arrangements, capable of operating in water depths of 200 m.

Most of the semi-submersibles recently delivered or presently under construction fashion a twin-hull, column stabilized platform as illustrated in Figures 5 through 8. The deck areas are virtually square, with the overall width of the twin hulls about double the height of the structure. The hull length may very depending on the self-propulsion system. These propulsion assisted units allow a reduction of the towing time and thus become more effective.Figure 9 shows one of these units in operation in the North Sea.

The operating depth of these newer twin-hulled rigs is almost invariably 300 m, thus allowing exploration of the Continental slopes. Actually, one of the most advanced twin-hull units to be placed in service in 1975 is designed to drill in a maximum water depth of about 600 m. Like all other semi-submersible

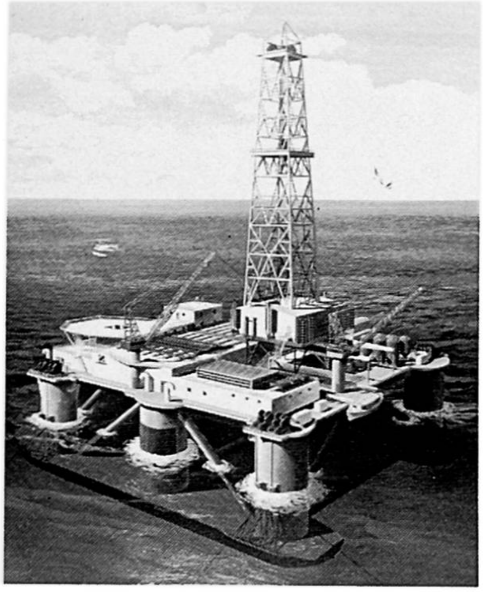

Fig. 8. Twin-hull supported Semi-submersible

Fig. 9. Semi-submersible in operation

Fig. 10. Self-propelled multiple-hull Semi-submersible

rigs this unit also uses a standard anchoring system to maintain location. However, because of the tremendous anchor forces of these deepwater units, future designs will probably use the principle of dynamic positioning.

A basically different rig design with an octagonal column layout develops its buoyancy through an orthogonal arrangement of multiple hulls as shown in Figure 10. This unit is self-propelled and can drill in water depths of 200 m. While en route only the longitudinal hulls are submerged, thus limiting the drag forces.

The steel framed semi-submersible units require that special attention be paid to the design of the truss system and the welded tubular connections. Hence rigorous analyses and model tests to determine the sea-going characteristics of these units and the associated member forces are of utmost importance. Great care should be exercised in developing appropriate joint design details, thus limiting stress concentrations wherever possible.

While semi-submersible drilling rigs have been built so far exclusively in steel, recently a design for a concrete drilling rig has been developed. This Condrill platform - as shown in Figures 11 and 12 - can be used for both exploratory drilling and as floating storage and production platform. The caisson type of structure consists of fourteen vertical cylindrical shells with external diameters of 8.25 and 15 m. These cells are poured in a single operation to form a monolithic unit. Six of the cells are capped, while the remaining eight extend above the waterline to support the double-level deck. The total concrete

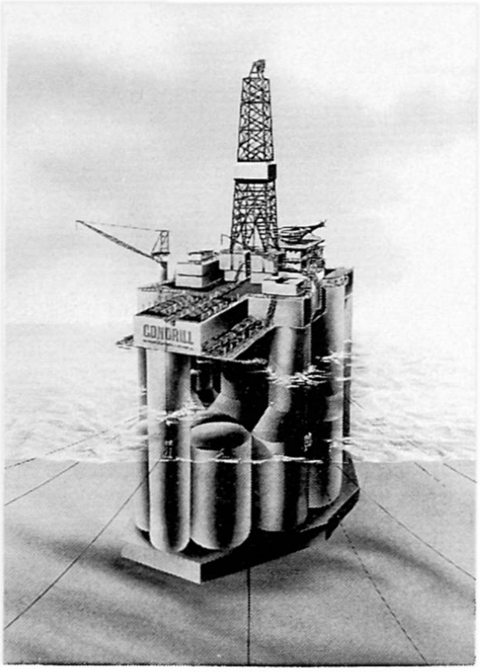

Fig. 11. Concrete Semi-submersible

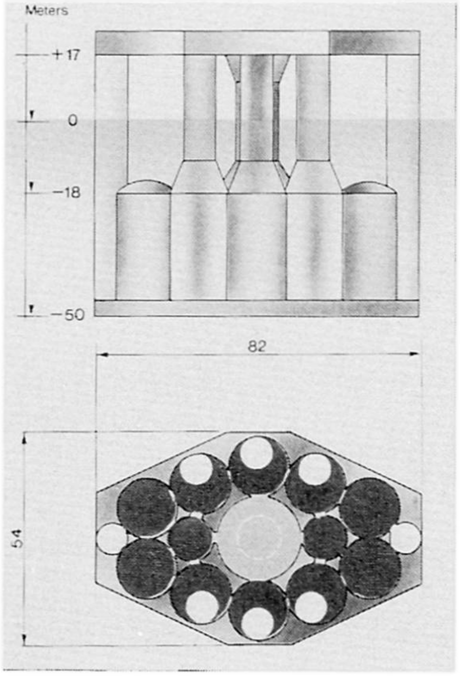

Fig. 12. Dimensions unit shown Fig.11

weight of the structure is about 50,000 ton, sixty percent of which is concentrated in the bottom slab. The storage capacity of this unit is listed as 2,000,000 barrels of oil. Drilling will take place through a 21 m diameter cell extending through the center of the platform. At the deck level this cell reduces to about 10 m in diameter. The unit is designed to operate in a water depth of 300 m and has a drilling draft of 50 m. Under tow this draft is reduced to 30 m.

DRILLING AND PRODUCTION PLATFORMS

Following the successful completion of the exploratory drilling phase, it is necessary to install a platform for the drilling of the production wells and subsequent production. These platforms have typically been designed as steel welded tubular space frames, called jackets. The vertical jacket legs, or columns, support the deck sections, while the diagonal or K-braces together with the horizontal web members provide the primary resistance against the lateral loads due to waves, currents, ice flow, wind and possibly earthquakes.

The smaller jackets - for water depths of up to 100 m - are invariably brought to the site on a barge and either lifted in position or launched off a barge. These platforms are subsequently anchored to the sea floor by driving steel piles through the inside of the jacket legs. The space between the pile and the inside of the leg is subsequently cement grouted to create an integral, well anchored truss structure. Next the deck units and operating equipment will be installed. The jackets are typically fabricated while in a horizontal position as illustrated by the North Sea Ekofisk jacket designed for a water depth of 75 m, (Fig. 13). A completed multiple platform unit located at the Leman Bank field (North Sea) is shown in Fig. 14. For most jackets the wells are normally placed outside the column legs, thus requiring conductor guide frames as shown in Fig. 13.

In case a platform is to be installed in waters with ice field movements, it is necessary to protect the well pipes by placing them inside the column legs. The absence of outside conductor pipes is illustrated by the three-legged platform located in Cook Inlet, Alaska (see Fig. 15). Furthermore, since it is necessary under those conditions that the web members do not pierce the waterline they should be restricted to the under-water portion of the tower. Because of

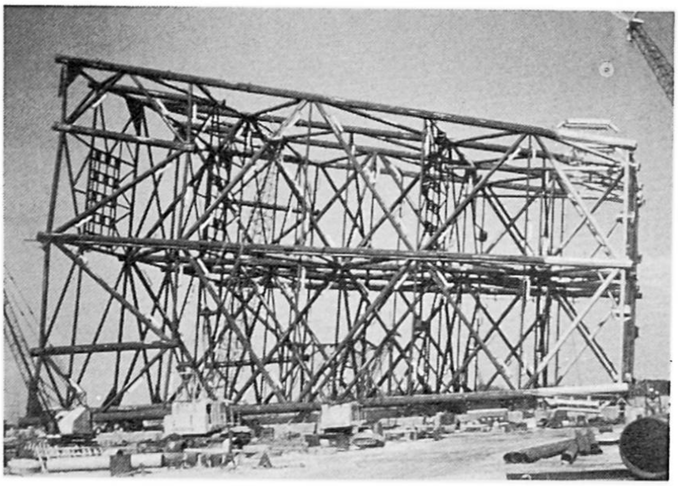

Fig. 13. Jacket at fabricating yard

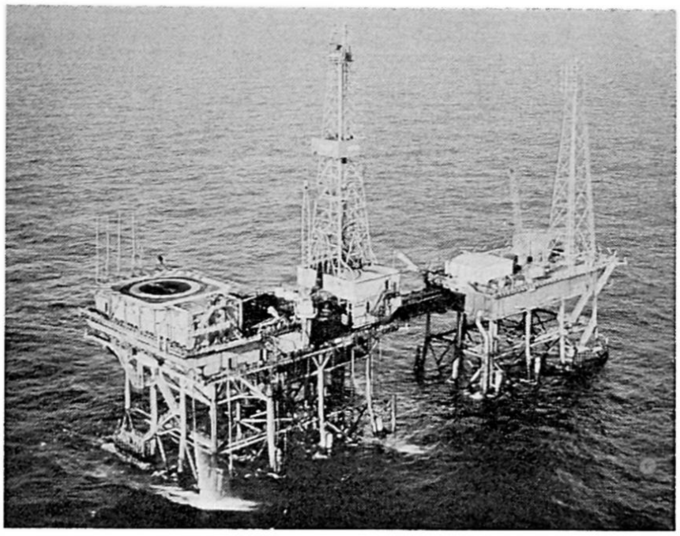

Fig. 14. Offshore Tower

the larger space requirements to locate piles and well pipes inside the jacket legs these sections are substantially larger in diameter as compared to the more standard units (4 to 5 m versus 1.00 to 2.00 m). The increased column sizes and large column surface loads require a substantial internal stiffening by either radial and longitudinal stiffners or by cement grouting the void spaces after installation, or both. These larger column dimensions provide sufficient buoyancy to float the jacket structure on its side. At location the jacket is upended by flooding the column legs as shown sequentially in Fig. 16 for a 32 conductor, four-legged Cook Inlet platform. Piles driven inside the legs secured the structure to the sea floor.

The largest steel jacket installed to date is the Highland One, a 145 m high structure standing in 127 m of water. This structure, which is one of the four jacket-type towers to be installed for production of the North Sea Forties field, was fabricated in a dry dock and floated out on its side while supported by a specially designed re-usable steel flotation unit (see Fig. 17). The jacket structure has a weight of 21,000 metric tons, while the flotation unit weighed 9700 tons. After the structure was tipped and sunk into place, the flotation structure was retrieved. Forty four 137-cm diameter steel piles, 73 m long and placed on the outside of the corner legs - note pile guides in Fig. 17 - secure the jacket to the sea floor. After placing the two-level deck modules together with the drill towers on top of the jacket, the total height of the structure will be about 220 m. The deck sections and auxiliary equipment, including piles and well conductors will weigh about 13700 tons. Hence, the total weight of the structure will be about

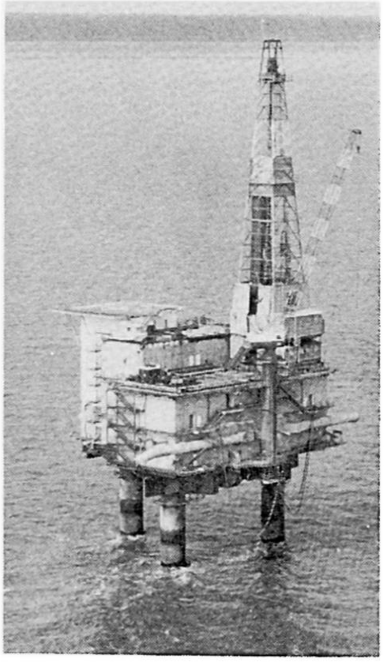

Fig. 15. Offshore Tower

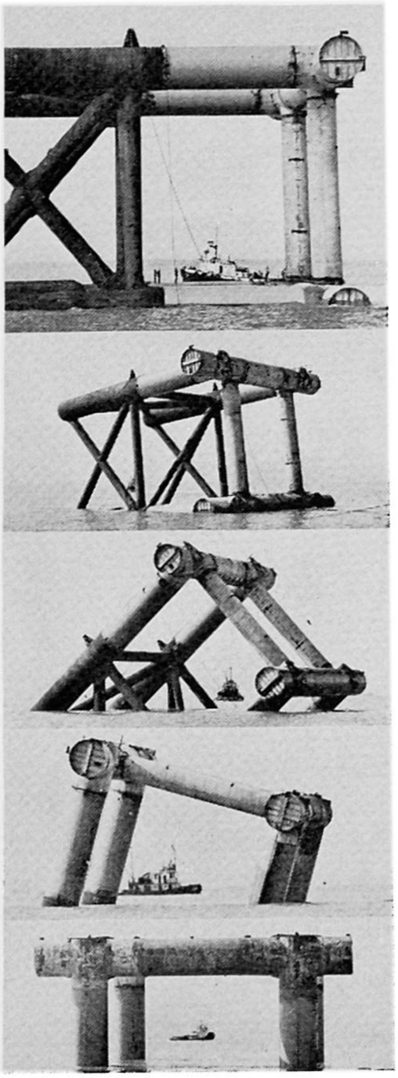

Fig. 16 Launching sequence

35,000 tons. The cost of this unit when completed is expected to be about $165 million.

The largest steel jacket platform presently under design will stand in the 162 m deep water of the North Sea Thistle field. The total height of this unit to the top of the flare stack is to be 280 m and the weight about 29,000 tons. This jacket will derive its flotation capability from two 9 m diameter legs and two additional cylindrical tanks, 82 m long and about 9 m in diameter, attached permanently to the two flotation legs. These supplemental flotation units provide a 70,000-barrel oil storage capacity when in operation. The daily production from the 60 wells to be drilled from this platform is estimated at 200,000 bbl.

The basic concept of oversized column legs on one side, in order to float the jacket out on its own buoyancy, is not new and has been used successfully before in platform designs offshore California. One of the critical aspects of the steel jacket-type platforms in a North Sea environment is the risk of upending the structure and the time and costs involved to drive the piles in order to tie the platform down to the sea bed. The latter time element reflects the risk that the jacket might be subjected to heavy weather before being properly anchored down. To reduce this risk, concrete gravity structures, serving as drilling, production and storage facilities, have been introduced in the offshore industry for the first time last year.

The concrete gravity units have the advantage that they do not need to be anchored to the sea floor because of their enormous dead weight - about fifteen times the weight of a comparable steel platform. Hence, the installation costs of concrete gravity structures - about 10% of the total cost - is considerably smaller than for the very large steel jacket platforms. The overturning movement under the most extreme sea conditions is completely counteracted by the structure's gravity. Under those circumstances it is imperative that the surface and near-surface soil conditions of the sea floor should assure the stability of the structure and soil. Hence, the soil layers should be horizontal in order to prevent sliding and to assure uniform consolidation.

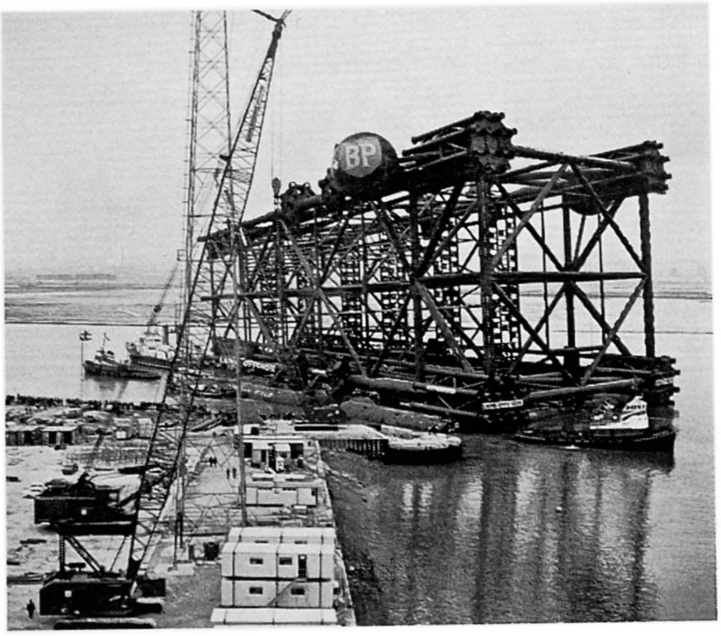

Fig. 17 Jacket on flotation unit

Since weaker layers may underlie stronger but shallower surface layers, deep skirts which are to penetrate the stronger upper layers and to develop the strength of the lower soils are commonly proposed.

The first concrete gravity structure is the 1,000,000 bbl storage tank which was installed at the North Sea Ekofisk field in 1973. Fig. 18 shows the structure while under construction and Fig. 19 gives a view of the tank as installed at the 75 m deep Ekofisk site. The tank is used for both production and storage. The inner tank complex, as illustrated in Fig. 18, is protected from the direct wave impact by an almost circular perforated breakwater wall.

The concrete gravity structures under construction at this time combine storage facilities, housed in a multi cellular system at the base of the structure, with the typical drilling and production facilities. The 1,000,000 bbl storage capacity of the Condeep design is provided by the nineteen vertical cylindrical tanks each with a 20 m outer diameter and a wall thickness of about 75 cm. The tanks are arranged in a pentagonal array as shown in Fig. 20. Sixteen of the tanks are capped at a height of 50 m, while the remaining cylinders form the base of the three post-tensioned concrete columns which will rise to about 20 m above still water and will carry the steel deck structure. (See Fig. 21). Of the five Condeep platforms presently under construction around the North Sea the first one ordered will be installed in 1975 in the Beryl field at a water depth of 110 m. Two other units are destined for the Brent field, where they

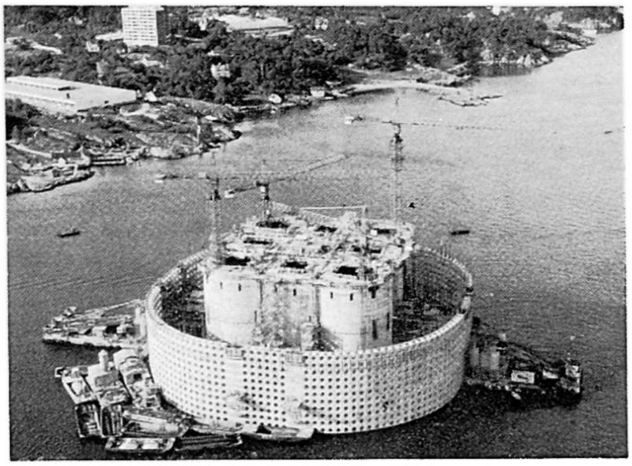

Fig. 18 Ekofisk tank under construction

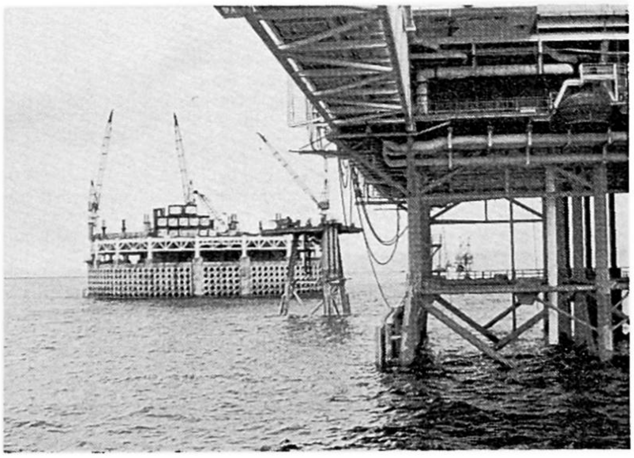

Fig. 19 Ekofisk tank installed

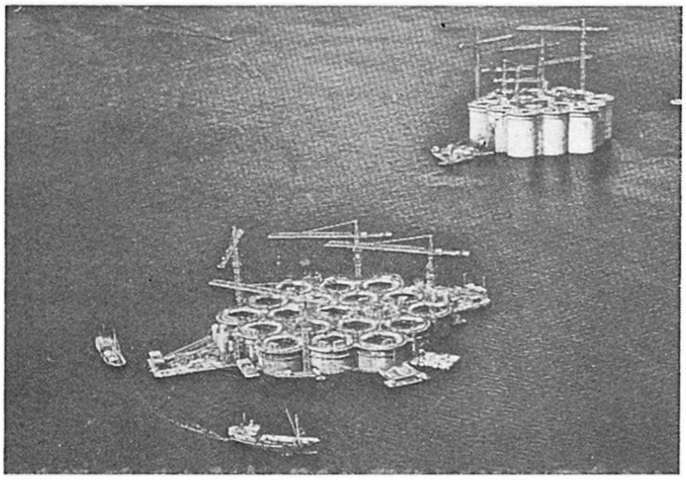

Fig. 20 Condeep Platform under construction

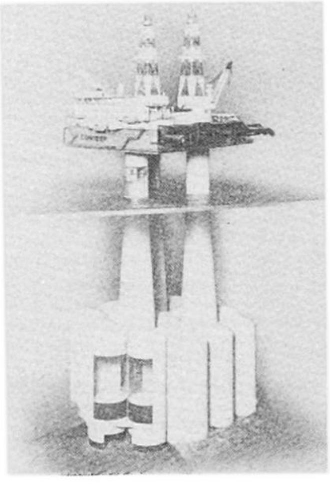

Fig. 21 Condeep Platform

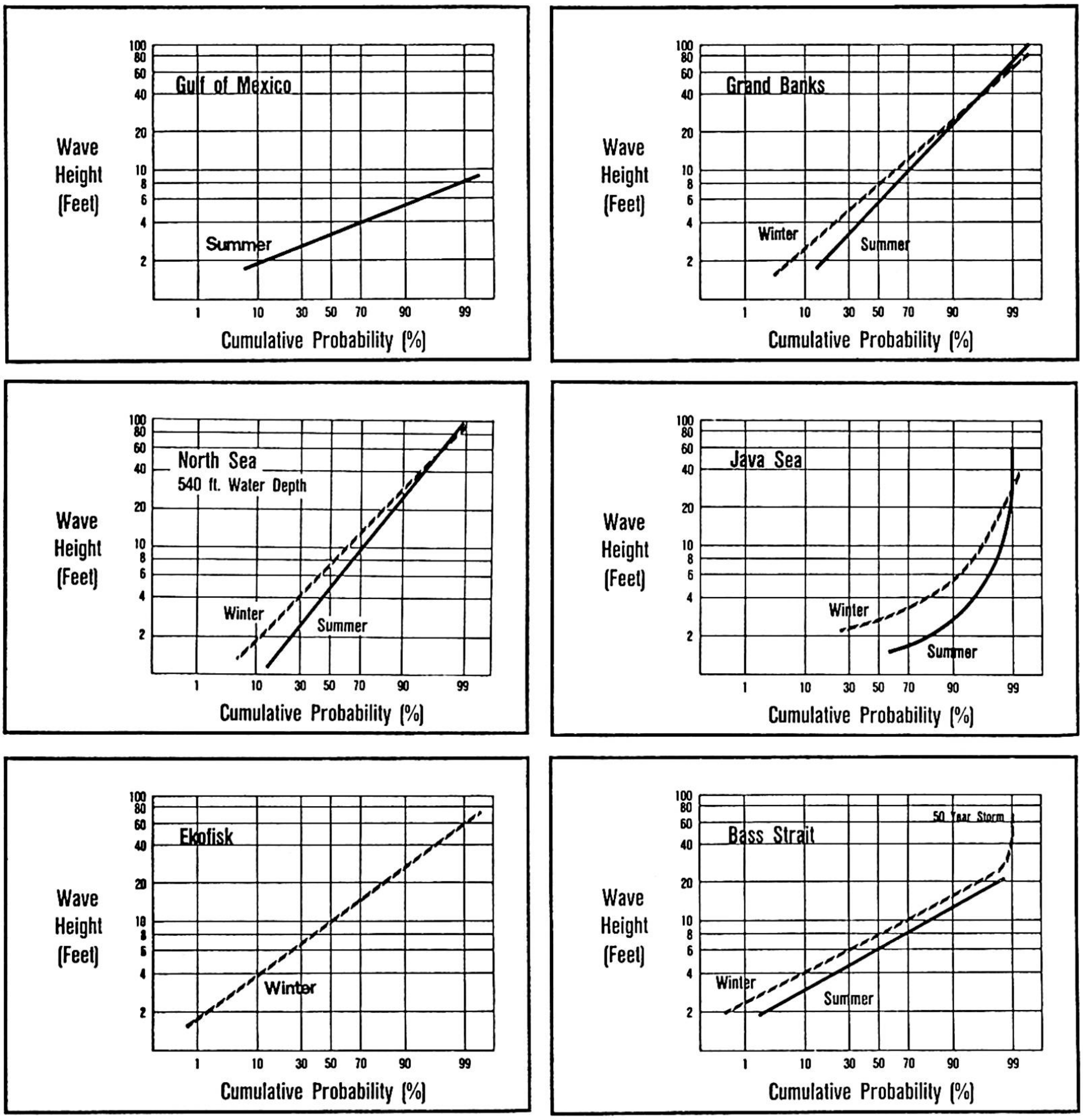

Fig. 22 Wave Data[1]

a steady operation of the barge and to prevent serious overstress in the line. Hence, larger more stable lay barges have been developed. Following the experience gained from operating the more stable semi-submersible drilling rigs, the modern pipelaying barges are also designed using the principle of semi-submergence. These units have lengths of up to 180 m and widths of 60 m. The greater deck lengths result from the requirement to handle double jointed pipes, allowing the barge to advance in larger increments. In order to design pipelines for these highly complex dynamic conditions, advanced programs of structural analyses, considering realistically both the elastic and potentially inelastic response

[1] Y. Goren,"Functional Design of Drilling and Construction Platforms," preprint 1973 Offshore Conference, University of California, Berkeley, California, USA.

of the pipeline during these pipelaying procedures are essential. Under those circumstances the associated structural design of the launching mechanism and the lay barge itself constitute an integral part of the overall design of these units.

DESIGN CONSIDERATIONS FOR OFFSHORE STRUCTURES

For the design of offshore structures the structural engineer has been and will be continually challenged to design for an environment which presents engineering complexities uncommon to the typical design considerations for land structures. In principle, structural design is determined by three major considerations, namely the environmental conditions of loading, the service requirements and the material properties. However, the final structural formulation will depend on the accuracy of specific analytical procedures which permit the evaluation of the structural response to any given set of loads. A design will be considered safe and functionally acceptable when the analytically-derived values do not surpass the limits set by the behavior criteria. The factor of safety to be reflected in these criteria, depends primarily on reliability of material properties, knowledge of design loads, accuracy of analytical procedures used to evaluate the structural response, serviceability, maintenance, and repair and replacement costs. The factor of safety can be reduced when engineering aspects as material properties and design loads are well defined and analytical procedures are highly reliable. On the other hand, economic factors associated with serviceability, maintenance, repair and replacement might well require an increase of the factor of safety. In the following sections, certain of the more important considerations in offshore design will be reviewed briefly.

ENVIRONMENTAL LOADINGS

The predominant environmental design loads are a direct reflection of the extreme sea state (waves, ice-flow, surface and tidal currents). The maximum design waves and wave spectra used in design differ significantly for different locations in the world. (See Fig. 22 and Table II.) Unfortunately, information of this nature is far from complete and often insufficiently accurate data has to be used to design drilling and stationary structures. The lack of this information is particularly critical in the design of drilling rigs which, during their design lifetimes, may have to operate in several different locations. Depending on the location, potential earthquake forces can play a predominant role in the design of stationary offshore structures. The study of offshore tower structures subjected to random earthquake excitations poses problems which are not encountered in similar land structures. Firstly, in the trussed ocean structures, the hydrodynamic forces on the structure introduce a non-linearity in the governing equations of motion, even when the material non-linearities are absent. Secondly, such structures have very high fundamental periods - from 2 seconds for towers in depths of about 120 m to over 5 seconds for those in depths of 300 m. This phenomenum prolongs the time to reach a stationary process. The response of offshore tower structures to earthquakes is, therefore, essentially a transient response. For the relatively more rigid gravity structures the non-linearity will be less severe. However, on the other hand the earthquake loads will be far greater and the capacity to absorb energy in a ductile fashion will be significantly less or non-existent.

MATERIAL CONSIDERATIONS

The previous aspects as applied to the design of relatively simple structures under well defined service conditions will normally pose little problem. However, for structures, which, because of the environmental circumstances will

TABLE II WAVE AND CURRENT DATA [1]

Location	100 Year Wave		50 Year Wave		Current Maximum Speed	Average Wave Height–Feet		Wave Height Above 10 Ft. Percentage
	Height Ft.	Length Ft.	Height Ft.	Length Ft.		Winter	Summer	
North Sea								
240 Ft. Water Depth	76	1093	74	1051		6.75	4.0	11.9
540 Ft. Water Depth	94	1394	89	1330	4.3 Ft/Sec.	8.33	5.65	22.8
Java Sea								
150 Ft. Water Depth	28		26.5		1.5 Knots.	2.62	2.25	Less than 1%
"Tsunami"–Max.	(100-135)							
Bass Strait			69 Highest 10%		2.2 Knots.	8.28	7.14	20.4
Gulf Of Mexico								
Eugene Island (88 Ft.)	53.5	949				4.87	3.83	Less than 2%
300 Ft. Water Depth	58	1232	48.5 (25 yrs)	986				
Grand Banks								
600 Ft. Water Depth	79		70 (25 yrs)		3 Ft./sec. 5 Ft./sec. (100yrs)	7.77	5.65	20.9

be subjected to severe and variable loads, advanced engineering judgment regarding the behavior and material properties is of decisive importance. Offshore structures, or ocean structures in general, fall undoubtedly in the latter category. The complexity of the design of such structures is not only affected by the environmental and material considerations but also by economic aspects. The need of advanced engineering principles is of utmost necessity to asses the economic feasibility of developing offshore energy resources.

The design of offshore structures normally considers load conditions under both towing and in-service conditions. One of the main loadings to be considered is undoubtedly the survival load which reflects an extreme storm or earthquake condition and depends on the projected life of the structure. This condition will normally be the governing factor in the design of fixed structures in shallow waters of relatively calm seas. However, when fixed and mobile offshore structures are to be exposed to hostile seas and are placed in deep water environments the typical survival design loads may well cease to be the decisive load condition. Particularly,if based on an operational service capability, the life expectancy of the structure has to be well defined. In that instance, the repeated loads causing relatively low cyclic stresses may well become a predominant factor in the design of the structure. In that instance, an optimum design approach to develop a fatigue-resistant structure has to be considered as well. This aspect may be particularly critical for steel structures and the design of tubular steel connections. A similar concern has also been voiced regarding the fatigue strength of reinforced and prestressed concrete in sea water. Corrosion and corrosion fatigue are important factors which affect the design of offshore steel structures. Cathodic protection has proven to be effective to improve the life expectancy of offshore structures. In case of concrete offshore structures, limiting crack widths will be necessary to prevent corrosion of the reinforcing steel and possible fatigue. Also cyclic temperature effects due to the storage of hot oil and cold sea water may pose certain problems in thick-walled concrete storage facilities. Information regarding the generally complex material problems in both steel and concrete is necessary to enable the structural engineering to develop an optimum offshore design.

will stand in water 140 m deep. These two structures should be installed by 1976. The base of these gravity structures are typically constructed in a graving dock. After the walls of the lower cylinders are built high enough so that the entire unit can float, the dock is flooded and the structure is towed to a deep-water site to complete the construction, including installation of the deck sections. A limiting factor in the construction of these units is the lack of sufficient deep water facilities.

In addition to the five Condeep structures under contract, six other concrete gravity structures are presently under construction. Three of these units are of the Sea Tank design while a fourth structure is designed by Andoc. The two designs are in concept similar to the Condeep design, except that the oil-storage base is square rather than pentagonal and the decks are supported by four columns rather than three. The two remaining structures are designed by C.G. Doris and are similar in concept to the original Ekofisk storage tank, using the perforated breakwater concrete wall.

Recently, also steel gravity structures have been introduced. Four structures designed by Technomare and intended for the 85 m deep Loango field near the mouth of the Congo River are presently being fabricated. These structures consist of a steel tubular trussed tower, with the six columns arranged in a pentagonal array. This tower structure is supported by a trinagular base truss with a flotation cylinder located at each corner.

With future exploration and production moving to ever increasing depths neither the steel piled jacket nor the gravity structure seem to be a feasible solution, particularly when the sea environment is very hostile. Hence, recent studies have been focused on the development of tension-leg platforms. One design would have a steel tubular trussed frame - in principle similar to the triangularly based semi-submersible drilling rigs as shown in Fig. 4 - held down by vertical pre-tensioned cables from each of the three corner flotation columns. Such a system would require deep-water sea bed anchors drilled into the ocean floor.

SUPPLEMENTAL OFFSHORE FACILITIES

In addition to the production platforms the development of offshore resources requires equipment necessary to bring oil and gas to shore. Foremost in this category are underwater pipelines and pipelaying barges. Pipeline platforms and offshore storage tanks play an integrated role in the oil and gas transportation system. However, from a structural viewpoint their design criteria are similar to the stationary structures discussed earlier.

Laying pipelines in calm shallow waters has been extremely easy as compared to the complexities of laying lines in deeper waters and under adverse weather conditions. The larger water depths (up to 200 m),the increasing distance to shore, the higher operating pressures and the larger forces require large-diameter thick-walled line pipes. The launching of these deepwater pipelines from conventional lay barges has become virtually impossible. Therefore new very large barges have been developed and are presently in operation. In order to guide the pipe from the barge deck into the water the so-called stinger, which provides a predetermined curvature to the line has become a standard feature of these modern lay barges. These stingers can be structurally articulated (multiply hinged) or be built in a few sections with adjustable roller supports. Under all circumstances it is essential that the line remains under tension to prevent collapse. While the stinger configuration and pipe tension permit a control of the pipe deformation, the sea state will be the ultimate limiting factor in the design of the line. The roll, heave and pitch of the lay barge should be minimized to allow

SUMMARY

The search for offshore oil and gas and the subsequent development has opened up an almost entirely new field of structural engineering. Several types of structures, often very large, have been developed for both exploration and production. The design of these units is highly complex and requires detailed information regarding environmental and service conditions as well as material properties.

RESUME

Les forages marins à la recherche de pétrole et de gaz, et les suites qu'ils comportent, ont ouvert un champ presqu'entièrement nouveau aux charpentes. Plusieurs types de structures, parfois gigantesques, ont été réalisées tant pour l'exploration que pour la production. Le dimensionnement de ces ensembles est extrêmement complexe et nécessite une information détaillée concernant les conditions d'environnement et d'exploitation, et les qualités des matériaux utilisés.

ZUSAMMENFASSUNG

Die Suche nach Oel und Gas im küstennahen Meer und die zugehörigen Entwicklungen haben ein praktisch neues Gebiet im Bauwesen eröffnet. Verschiedene Typen von oft gewaltigen Bauwerken wurden für Suche und Förderung entwickelt. Entwurf und Berechnung derselben ist in hohem Masse komplex und erfordert eingehende Information über Umwelts- und Betriebsbedingungen sowie über Materialeigenschaften.

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